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A DEFINITION OF CAUSATON. III

IN the two preceding papers we have carried out the empirical method of investigating the meaning of causation through the field of statics, and through part of dynamics. In accordance with the plan drawn up in the first paper, we shall now continue the inquiry through the remainder of dynamics, the "properties of matter," and the field of electricity. These, we decided, offer in the present state of science the only types of causal connection which are deserving of analysis, since all other types are reduced to some or all of these three. The next case in order is that of

Impact

This may be viewed as a case under Newton's second law, if we consider the acceleration given by one of the bodies to the other: if we consider the motion of both bodies before and after the collision, it falls under the third law. It seems to be a typical case, in dynamics, of action and reaction between moving bodies. The interest of it lies in its being treated as the type *par excellence* of *all* causation, by those who defend a mechanical philosophy of nature. Some, though not much, work has been done toward analysis of it in monographs little known to English-speaking philosophers.[1] This case also differs from anything previous in being more complex. There appears to be a decided change of quality between cause and effect, in contrast with the simple uniform series and the simple combination of two forces into one, which were examined in the last paper.

We shall begin with an artificially simple case. The bodies are supposed smooth and non-rotating perfect spheres, perfectly elastic or imperfectly elastic. The question, whether there is actual contact, may be neglected.

Elastic smooth spheres in direct collision, where there is no rotation, obey the following law. If the bodies have, respectively, masses

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[1] R. Schellwien, "Das Gesetz der Kausalität," page 17; A. Kowalewski, "Ueber das Kausal Problem," pages 14–17; A. Farges, "Theorie Fondamentale de l'Acte et de la Puissance," pages 223–24; *et al.*

A and B, velocities u and v before collision, U and V after collision:

$$Au + Bv = AU + BV.$$

$$u - v = V - U.$$

$Au + Bv$ is the total momentum of the two bodies before collision; when they are moving in the same direction Bv is positive, when in opposite directions Bv is negative. In the same way, $AU + BV$ is the total momentum after collision. This means that whatever momentum A loses is taken up after collision by B, and conversely. For $Au - AU = BV - Bv$, where the left-hand member is the loss in A's momentum and the right hand member the gain in B's momentum. At contact with B, A's momentum is simply split into two parts and one of them transferred to B. It is analogous to a resolution and subsequent combination of forces, except that it here applies to momenta and occurs in the same straight line. The two parts of the whole process, before and after impact, thus reveal identity at every stage, in spite of the apparent difference. But the identity is yet more complete. The total momentum is not only the same throughout, but it travels along in the same direction and at a uniform velocity. It is going just as fast before the impact as during the impact and after the impact. That is, the center of mass of the whole system (a property already accounted for by the principles of statics) moves onward continuously at a steady rate. Its velocity is easily found to be $(Au + Bv)/(A + B)$. The whole system, then, is a case of the first law of motion: even the individual momenta considered by themselves are preserved, though the same velocity does not continue with the same mass. The reason why the case of impact seems irreducible to one of the first law is that velocities suffer change after impact. It is a reason analogous to that which made composition of forces seem paradoxical. One line can not by itself *be* another line, we admitted: but when it is considered from the point of view of its relations to other lines, it can have several directions at once. So here: the velocities before and after impact are different; but when we remember that velocity is not something by itself, but is *of a particular mass*, the later velocity may be seen to admit a possible identity with the earlier velocity. The transfer of a velocity unchanged from one mass to another greater or less mass is *not* the transfer of something identical from one situation to another; for the same velocity of a greater or less mass is a very different thing. In the case of a uniform motion under the first law, the mass is constant and hence the velocity persists unaltered: but it did so because it was the velocity of a constant mass. Here, too, the velocity is preserved, but because it is the velocity of a different mass after impact, it assumes a different value. The loss in velocity of A is $u - U$; the gain in velocity of B is $V - v$; but $V - v = (u - U) \cdot A/B$. The velocity which B gains is just that which A lost, adapted to the mass of B. The apparent differences are then due to the original elements of the event persisting in new circumstances.

We can represent the whole process as a series whose elements x are successive positions of the momentum of A; at the instant of impact this is resolved, but the sum of the resolved momenta continues this series uniformly onward. Thus:

$$x_1, x_2, x_3 \cdots x_n \left(= \begin{matrix} x_{A_1} \\ x_{B_1} \end{matrix} \right), \quad x_{n+1} \left(= \begin{matrix} x_{A_2} \\ x_{B_2} \end{matrix} \right) \cdots.$$

And we may do the same with the successive positions of the momentum of B; and with the motion of the center of mass of the whole system. This reduces the case to one of the first law, with the principle of resolution included. No new type of causation is found here.

Of wholly inelastic bodies in direct collision the same holds. The differentia of this case is that, instead of $u - v = V - U$ we have $U = V$. The bodies do not rebound, and consequently move on together after impact, in the direction in which the body with the greater momentum was moving. Just as with elastic bodies, the loss in momentum of A is gained by B, the center of mass moves onward uniformly, the velocity is transferred, adapted to B, and a resolution of momenta occurs along the line of motion. The kinetic energy after the collision is less than before, because some of it has gone into heat in the bodies; but the momenta are preserved just as with elastic bodies. Consequently—with the exception of this transfer to heat—this case is of the same type as above. Now the phenomena of heat are explained by physics on the supposition that it is motion of the molecules of a body. It presumes that the kinetic energy, *i. e.*, half the squares of the velocities times the masses, of all the particles of the bodies, which is not continued in the form of molar motion after the impact, could with sufficient knowledge of detail be equated to the same function of the internal motions. Even here, then, there is believed to be no exception: the motions of masses continue undestroyed, though we can not trace the causal sequence in detail. Of partially or imperfectly elastic bodies,—which comprise all known actual cases—the equation $u - v = V - U$ becomes $e(u - v) = V - U$, where e is the "coefficient of restitution," representing the amount of return to its original shape of a body after the deformation due to impact. The introduction of e is indifferent to the conservation of the momenta; it simply determines the amount of kinetic energy transformed into heat. For the way in which elasticity acts we may refer to the later discussion. Apart from that, no new principle is involved.

Oblique collision is treated by the same methods as direct collision, *after* the velocities have been resolved into suitable components.[2] It is, therefore, a combination of the above types with that of the type of resolution of velocities, and offers nothing new for our purposes.

Change from Potential to Actual Motion and the Converse

When a body is shot upward from the earth's surface with a certain initial velocity, that velocity decreases uniformly until the body reaches the highest point of its journey, passes through zero velocity, and returns with uniform acceleration. Let us suppose the rise and fall of the body to be exactly vertical. Imagine also that at the turning-point of its flight a rigid support is suddenly thrust under it, fixed there for a time, and then removed. This furnishes a clear picture of the change from actual to potential motion and the converse. The whole process is subject to law and is, therefore, causal throughout. What is its make-up?

As the body flies upward to its highest position, each stage through which it passes is compounded of two causal processes—the attraction of the earth and the continuation of initial velocity—each of which processes conforms to the type already described. We need not concern ourselves further, then, with this portion of its flight. The velocity which results, at every stage, decreases regularly until it has the value zero. If no support were put in, it would pass through the zero value and become negative, *i. e.*, a velocity of contrary direction. The whole series would thus be quite analogous to the case of pressure at one end of a bar balanced on a fulcrum, which is transmitted to the other end of the bar; a case examined under the head of statical causation. But when the support is thrust in, the motion ceases for a finite period of time. The body is then said to have potential energy due to its position, or the work already done in raising it. The downward motion does not exist; no motion exists, and there is said to be a *tendency* to move downward.

Observe first that this is a real condition, and an identifiable one, described by more than the word *rest.* The body exerts *pressure* upon the support, and this pressure *is* its potentiality. When the physicist speaks of this potential energy as something "metaphysical"[3]—meaning, of course, inaccessible to observation—he is, I venture to think, more modest than is necessary. Pressure might be objectively as real as form and size. There is no reason *a priori* why the content of touch-sensations should not be as objective as the qualities given in visual sensation. The thing is a question of fact.

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[2] *Cf.* Williamson and Tarleton, *op. cit.*, pages 70–72.

[3] Thomson's and Poynting's "Heat," London, 1911, page 116, note.

Is there evidence that pressures continue—as colors, sounds, etc., do not—when we do not perceive them? There is such evidence. *Whenever* the support is removed, the body falls. Therefore it was pressing downward, tending to fall, all the time. Its existence is as objective as motion is, and as independent of our perception; it is not a "secondary quality." In fact, the reason assigned for believing in potential energy by the authors above referred to is that the energy of motion which is lost appears again when the body falls;[4] just the reason why we believe in the existence of the bodies themselves when we look away from them.

As soon as the support is placed under the body, a composition of forces occurs, giving equilibrium. The downward pressure of the body is exactly equal to the upward pressure of the support. The series of velocities constituting the hitherto motion continues, but is at this point compounded with another series; the continuous upward push of the support. It is the same sort of thing that we found in the collision of bodies. *There* the uniform motion was not destroyed, but compounded at the moment of impact with another uniform motion. So here, the series of velocities in the rising body continues, but is compounded with the resistance of the support and, as it were, turned in a different direction. The potentiality here is simply a special case of composition, such that the forces compounded are equal and opposite. In fact, we might define potentiality as equilibrium. Nothing whatever is destroyed; rather something is added to each of the factors, *viz.*, the opposite factor. This explains the familiar Thomistic-Aristotelian doctrine that a potentiality by itself is never a cause of an event; for nothing happens unless the equilibrium is destroyed. It agrees also with Ostwald's second law of energetics, that no event occurs unless there is an uncompensated difference of potential factors; since an uncompensated difference is equivalent to the fact that there is no equilibrium. Or, again: "when the parts of a body or of a system of bodies are in any degree free to adjust themselves under forces that exist within the system, they will always so arrange themselves as to make the potential energy of the system as small as possible,"[5] *i. e.*, the differences compensate themselves as far as possible. So far, then, there is a continuation of the original series plus a compounding of it with the pressure of the support.

As soon as the support is removed, the composition is succeeded by a resolution. The support no longer combines with gravitation to produce equilibrium, and the latter force acts alone in the manner stated under the topic of gravitation. In the whole process, from beginning to end, there does not seem to be any new type of causation besides the serial type and the type of composition.

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[4] *Op. cit.*, page 110.

[5] D. W. Hering, "Essentials of Physics," New York, 1912, page 45.

This completes the list of cases under mechanical causation. It will be observed that the principle of composition plays a large part; so large, indeed, that all the complex cases are reduced to simpler types by its aid (or that of its closely allied form, the principle of resolution). A principle so ubiquitous and so useful would seem likely to have some philosophical significance. In the writer's opinion it has; and accordingly before passing to the topic of "Properties of Matter" we had best pause to consider that significance.

A Generalization from the Principles of Composition and Resolution

We have seen that a combination of forces may really contain the components intact. They may, in combining, pass from the actual to the potential state, or the converse, or may be combined as already potential and remain so, or as actual and remain so. This is philosophically a significant result. One philosophical objection to the objective reality of the scientific concepts is based on the assumption that they are not, when combined as they are in reality, preserved in the same form as they have when treated alone. Now, as a result of empirical investigation we have found that this is not true. They are at least sometimes so preserved. As a *general* criticism of science, then, this philosophical view should not stand. When, however, the view is based, not on an assumption which can not be verified, but on an ultimate doctrine of internal relations, it is a different matter. Such a view declares that whether parts are changed or not when combined into wholes, the ultimate metaphysical *account* of the parts must be formulated in terms of the whole. That is not inconsistent with the empirical facts, and shall not here be discussed. Our only present concern is to point out that if science is not metaphysically ultimate, it is not because the parts with which it deals fail to exist. The analytic treatment is true to existence.

A corollary of some importance to the philosophical estimation of our present method is that it is right (barring dialectic, etc.) in treating types of causation singly. In the manifold and very complex combinations of them which constitute real individual events, each kind of causation may well be preserved intact. The artificially simplified laws of the text-books may never be realized alone, but they are real *tendencies* and sometimes real *processes,* working uninjured by the environment with which they combine. Had the deniers of the existence of abstractions considered the detailed empirical evidence, they would, perhaps, have avoided such a doctrine.

Are there, then, real rigid bodies, projectiles moving in straight lines or perfect parabolas, totally inelastic bodies, etc.? There are bodies whose tendency to behave as perfectly rigid, etc., combines with other tendencies to produce a resultant which is not as a whole the behavior of a rigid body, etc. The abstract concepts of science denote, in general, real tendencies in Nature, which are never destroyed or lost, but combined with other and often opposing tendencies. We may say, if dialectic, idealism, or other views command it, that science does not deal with ultimate reality; but we should not, it appears, say that science deals with the non-existent. Tendencies exist as much as anything else.

This completes the list of cases under mechanical causation. We pass next to the second of the three groups marked out above.

II. Properties of Matter

1. *Elasticity*

The elasticity of gases and liquids depends upon that of the solid particles composing them; so we need examine only the properties of elastic solids.

An elastic solid has the following property: "if the applied forces and the consequent strain [of the body] be confined *within certain limits,* the body offers continuous resistance to the strain, so that *it requires the continued exertion of external force* to maintain the body *in a given state of strain*; and when this force is removed the body *tends to return* to its natural state . . ." other conditions being equal.[6] Also "It always requires the same force (or system of forces) to maintain the same strain at the same temperature . . ." (p. 6). This, however, holds only of perfectly elastic solids; it is not a universal law of matter. Even a very elastic body has its *limits,* such that any strain greater than a certain amount renders it *ductile.* "In this condition the resistance still increases with the strain, but much less rapidly than before the limit was passed, and the tendency to return towards the natural state is much diminished, so that, when the external force is removed, the body is found to have acquired a 'set' or *permanent strain*" (p. 4). Beyond this region of greatly diminished elasticity lies breakage; sometimes, as in the case of brittle bodies, breakage supervenes almost directly upon the elastic limit. Also, "by sudden and violent changes of temperature, many substances, and notably metals and glass, may be entirely altered in all their elastic properties" (p. 5), which property "is obviously analogous to that [change] produced by straining it beyond its elastic limits" (*ibid.*). But even *within* the limit, resistance to strain varies with the rate at which the strain is imposed, as well as with frequency and recency of strain (fatigue).

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[6] W. J. Ibbetson, "Mathematical Theory of Elasticity," page 4.

We may, then, classify the events that occur in this domain under two heads: (1) cases of approximately perfect elasticity, such as the behavior of metals, crystals, glass, jellies, etc., within their elastic limits, not subject to viscosity or fatigue or "temper," and (2) all other cases, including even approximately inelastic substances such as tallow, putty, etc. Let us discuss these separately.

1. The elementary event is this: when a certain force has been applied to a body, followed by a change of shape or volume, then upon release the original volume or shape is restored. Scientists believe that there are certain intramolecular stresses which bring about this restoration. This is in itself no more mysterious than gravitation, which pulls back to earth a raised body. But it is not known how these forces move the particles of the elastic body; with what velocity and acceleration or with what relation to the mass or displacement. The behavior of gravitating bodies has been accurately described and measured, and found to conform to Newton's first law; but of the molecular behavior of elastic bodies we know little or nothing, and can not say whether it reduces to a mechanical or to some other type. We must wait for further evidence.

2. The other cases confirm this statement. The intramolecular forces do not always work. Sudden strain, too great strain, too prolonged or recent strain, etc., render them ineffective, or nearly so. Why this is so, is not understood; which is only another way of saying that the nature of the molecular stresses is not known. If we knew their behavior we should know how it is that these conditions affect it. Here, then, the result is disappointing. We get no data for causal analysis.

Nevertheless, so far as the behavior of these forces *is* known, we may say that it is a case of potential energy leading to kinetic energy, the latter being that of the motion undergone by the particles in restoration to the original shape and volume. The potential energy becoming kinetic is a case of the kind already considered under dynamics. It appears to be an energy of position, giving rise to motion of masses upon release of the detaining force.

2. *Friction*

This is of two kinds, sliding and rolling friction. Sliding friction is explained thus: "When one of the bodies tends to move over the other, the projections interfere and tend to stop the motion."[7] Why the coefficient of friction is different in different substances is known only in a general way, *viz.*, some substances are rougher, have more projections, more rigidity, than others. No exact explanation of the particular values of coefficients is at present available. That there

[7] E. L. Hancock, "Applied Mechanics for Engineers," page 261.

should be such a thing as friction seems, from the above explanation, to be due to the fact that bodies resist change of shape. The motion is then transformed into heat, *i. e.*, motion of the particles: this reduces to a case of impact, therefore, and is a dynamical type. When a body resists change of shape or breakage, we have a case of cohesion—of which later. That sliding friction is nothing more than these, is indicated by the laws of Morin: the friction between two bodies is directly proportional to the pressure, and independent of the area of contact.[8] For increase of pressure means increase in the number of collisions between irregular projections in the surfaces. And the fact that static friction is greater than kinetic is due to the fact that in the state of rest there are more points of contact between the two bodies—owing to the sinking of the upper body on the lower —than in the state of motion. As far as sliding friction has been analyzed, then, there are no types of causal connection found but mechanical ones.

When the surfaces are lubricated, "the projections of one do not fit into the other, but are kept apart by a film or layer of the lubricant."[9] Here it is not a matter of collision between projections, but of internal friction in the lubricant, of the attraction of its particles for one another, of their adhesion to the surfaces of the bodies, and of the substitution, in part, of rolling friction for sliding friction. The events herein involved—except for the rolling friction—come under the head of molecular attraction and cohesion: of which later.

Rolling friction depends upon deformation of one surface by the pressure of the other: a wheel is flattened by the road and the road depressed under the wheel. Instead of collisions we have pressure. When the road-surface is very elastic, the depression is relatively deep, and the road rises immediately behind the wheel almost as steeply as in front. The depth of the depression here occasions slipping, *i. e.*, sliding friction; the case just considered. The unique characteristic of rolling friction is, then, resistance offered by pressure, and the causation is here statical and dynamical.

3. *Resistance of a Medium*

This situation is due partly to inertia of the particles of the medium, and partly to another factor classed with friction under the head of "passive resistances."[10] "If a mass m be supposed to move in a straight line, without rotation, in a resisting medium, the resistance is a function of the velocity of the body. . . . If the resistance be represented by $\phi(v)$, the equation of motion becomes

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[8] *Op. cit.*, above, page 263.

[9] *Op. cit.*, page 265.

[10] Minchin, "Statics," page 75.

$$m\frac{dv}{dt}=F-\phi(v),$$

where F is the external force acting along the right line. It is usual to assume, with Newton, that $\phi(v)=\mu v^2$, where μ is a constant depending on the density of the medium.''[11] This law, however, is of limited range; in some cases the resistance increases with higher powers of the velocity. The causes are, in fact, unknown; we can not tell in detail how the resistance acts. The data give us no definite type of causal connection.

4. *Density*

This property is not regarded as explained, except, in the case of gases, by the number of molecules. Its causes are believed to lie in the structures of the various substances, but just where or how is not known. No material is here given us for analysis.

5. *Cohesion*

This is believed to be a general property of matter which probably reduces to molecular attraction of some sort, but whose detailed behavior and laws are little known. If two smooth surfaces are pressed together very hard they tend to adhere as if glued. Gluing makes bodies adhere because, after drying, there is very little space between the particles. ''There is no real difference between adhesion and cohesion.''[12] Unfortunately, this amount of information will not suffice for a causal analysis.

6. *Gravitation*

The source of this property is also unknown, though theories are extant.[13] It is also unknown whether or not it acts instantaneously. It is believed, however, to act uniformly in a straight line, for it obeys the law of inverse squares, like light, radiant heat, and many other phenomena which proceed in straight lines. The law of inverse squares is a simple deduction from the property of action uniformly in a straight line, as that action radiates in all directions from a given body in space. The mode of action of gravitation, then, is analogous to that property of uniform motion by which it continues uniform in a straight line. Its type of behavior will, therefore, come under the same serial description as uniform motion (discussed in the preceding paper).

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[11] Williamson and Tarleton, ''Dynamics,'' page 219.

[12] Ganot's ''Physics,'' Eng. tr., 18th ed., page 10.

[13] *E. g.*, W. Sutherland, in *Philos. Mag.*, December, 1904.

7. *Crystallization*

"Definite chemical compounds almost always possess *some* power to crystallize, though certain usually crystallized substances may be made to assume an amorphous [non-crystallized] form by very much accelerating their rate of solidification . . ." "Substances which are only known in the amorphous state are usually of indefinite chemical composition, like coal, amber, or opal."[14] Crystallization thus appears to be a general property of matter, so far as it possesses definite chemical structure. As to its make-up: "The physical behavior of crystals . . . necessitates *units of structure*, or elementary particles by whose regular arrangement the crystal is built up. As such units we may assume the physical molecules . . ."[15] "If the crystal elements or physical molecules of a given substance possess the same size and the same attractive forces, then, in case these molecules are perfectly free to act and react upon each other, they must all assume a similar position relative to one another, *i. e.*, such a position that equivalent directions of attraction and repulsion in all the molecules shall be parallel" (p. 5). That is "*the grouping about any molecule must be the same as about every other*" (p. 6). "Thus the study of crystal structure becomes an investigation of the possible networks of points in space which satisfy these conditions" (p. 6). In other words, this situation is one of statics and dynamics. The causes of crystallization are "molecular forces which tend to produce a regular internal structure in matter as it slowly solidifies," and these forces are conceived to act under the laws of statics and dynamics.

Further, "we may have crystals identical in composition and in all their physical properties, but bounded by very different sets of planes, all of which are equally possible with the same internal structure. Such differences in form among crystals of the same substance condition what is known as *crystal habit*" (p. 12). "Exactly what it is that determines the habit of a crystal is not known" (p. 13). "*The growth of crystals, i. e.*, the relative development of the different faces, is very variable, and often irregular. . . . The conditions controlling these distortions are not well understood."[16]

So far, then, there does not seem to be any definite type of causal process in the formation or the growth of crystals, over and above those already discussed. The nature or origin of the molecular forces is not known; their mode of action in determining structure is mechanical; "habit" and growth are not understood.

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[14] G. H. Williams, "Elements of Crystallography," page 7.

[15] *Op. cit.*, page 4.

[16] W. Nernst, "Theoretical Chemistry," page 79.

8. *The Principle of the "Indestructibility of Matter"* (*i. e., of Mass*)

"Numerous investigations have shown that neither by physical change of a substance, as, for example, by pressure, heating, magnetization, etc., nor by chemical decomposition, does there occur a variation of its mass as measured by the attraction of the earth."[17] In fact, the whole atomic theory of chemistry is a reduction of apparently diverse facts to terms of ultimate permanent units. This is on a par with what we found in physics, as to conservation of momentum. From the point of view of a series of instants or short periods in time, the unchangeable character of mass appears as a process whose logical structure is the same as that of the series describing uniform motion, inertia, etc.

The principle of the conservation of energy seems obviously to come under the same rule. It is, however, so broad and general and, where formally stated, so lacking in concrete detail that by itself it gives but a faint idea of the operation of causation; hence we content ourselves with this brief mention of it.

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REGULATION IN BEHAVIOR

SEVERAL years ago there appeared in *Nature* an account of a statistical inquiry into sex determination. The results indicated that children born to young mothers were predominantly girls and that those born to old mothers were predominantly boys. Whether this hypothesis has been borne out by further results I do not know, but, assuming it to be a law, it is an example of what has been called regulation in behavior. The purpose which such a process serves is clear. When there is a shortage of women in a community girls are likely to marry when very young, due to the increased opportunity afforded them on account of the under-supply of more mature women. If such marriages result in a number of female infants greater than the normal expectation, the balance between supply and demand is thereby reestablished. A similar compensation is had when, in a society where females predominate, and hence are not married so early in life, male offspring are in excess.

The world is full of instances of this sort. Organisms utilize the very difficulties they encounter in order to bring about the removal of these difficulties. Their make-up insures this regulation. They do not depend on outside guidance to carry them through adverse situations. The adverse situations in combination with an organism

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[17] W. Nernst, "Theoretical Chemistry," Eng. tr., page 4.